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COMPARISON OF STRUCTURAL EFFICIENCIES OF DIAGONAL-TENSION WEBS AND TRUSS WEBS OF 24S-T ALUMINUM ALLOY

By David W. Ochiltree

Langley Memorial Aeronautical Laboratory
Langley Field, Va.

NACA

WASHINGTON

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COMPARISON OF STRUCTURAL EFFICIENCIES OF DIAGONAL-TENSION WEBS AND TRUSS WEBS OF 24S-T ALUMINUM ALLOY

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SUMMARY

A comparison is made of the structural efficiencies of truss webs of 24S-T aluminum alloy with previously published values of the structural efficiencies of diagonal-tension webs of 24S-T aluminum alloy on the basis of identical allowable stresses. It is concluded that the diagonal-tension beam (web and flanges) can usually be built to be a more efficient beam than the truss beam, even though over a small range the web of a Warren truss beam is slightly more efficient than the web of a diagonal-tension beam.

INTRODUCTION

The structural efficiencies of truss webs and diagonal-tension webs have often been compared. In many of the comparisons made, the diagonal-tension web has been shown to have a low structural efficiency because conservative design formulas and conservative allowable strength values were used in the design. On the other hand, the efficiency of the truss web in some cases has been lowered by arbitrarily fixing the slope of the diagonal truss members at a value that gives a low structural efficiency.

The structural efficiencies of diagonal-tension webs of 24S-T aluminum alloy were examined in reference 1 by use of a coordinated set of formulas that were based on a series of strain surveys and checked against the results of more than 120 strength tests. Because these formulas are based on a large number of tests, the formulas and, consequently, the structural-efficiency values obtained should be reasonably accurate.

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In the present paper, the structural efficiencies of Pratt and Warren truss webs that are designed on assumptions similar to those used in reference 1 are investigated and compared with the structural efficiencies obtained in reference 1 for diagonal-tension webs.

SYMBOLS

S transverse shear force in web, kips

V volume of web material per inch run, inches squared

h effective depth of beam, inches

d spacing of uprights, inches

t thickness of diagonal-tension web uprights or truss-web members, inches

b width of outstanding leg of diagonal-tension web uprights or square-tube truss-web members, inches

BASIC DESIGN DATA

In order to obtain a fair comparison of the structural efficiencies of truss webs and diagonal-tension webs, the basic design data for the truss webs were made similar to the data used in reference 1 for the diagonal-tension webs. Briefly, the basic design data for the diagonal-tension webs, as given in reference 1, were as follows:

> The web and upright material was 24S-T aluminum alloy. The allowable strength values and the column curve for this material were taken from reference 2. The web uprights were assumed to be simple angles with a width-thickness ratio of the outstanding leg of $\frac{b}{t} = 12$ to eliminate the possibility of local instability of the free edge. The effect of rivet holes on the web strength was taken into account by using a rivet factor of 0.80 in the calculations.

The basic design data for the truss webs were as follows:

> The material was 24S-T aluminum alloy. The allowable strength values and the column curve for this material were taken from reference 2 and were therefore identical to the values in reference 1 for the diagonal-tension web. The truss members were assumed to be square tubes with a width-thickness ratio of the flat-plate elements of $\frac{b}{t} = 24$ to eliminate local instability. Truss members acting in compression were assumed to have pinned ends. An average effect of rivets and gussets on the structural efficiency of the truss webs was determined by designing riveted joints for several truss webs and calculating the resulting increase in the truss-web weight.

RESULTS OF EFFICIENCY STUDIES

On the basis of the design data outlined, several Pratt and Warren truss webs were designed such that the tension and the compression members would fail simultaneously. Because the efficiency of a truss web is a function of the slope of the diagonal truss members, this slope was varied until the most efficient truss web for a given depth and loading was found. The calculations showed that, over the range investigated, the slope of the diagonal members for the most efficient Pratt truss web varied from an angle of 57.2° to 62.3° with the vertical and, for the Warren truss web, from an angle of 40.5° to 43.8° with the vertical.

Curves of the structural efficiencies of Pratt and Warren truss webs are shown in figure 1. The measure of the structural efficiency is the ratio of the transverse shear force in the truss web S to the volume of material per inch run V. The ratio S/V is plotted against the structural index $\sqrt{S}/h$, where h is the effective depth of the truss beam. The solid lines in this figure are for ideal truss webs in which the effect of rivets and gussets on the truss efficiency is neglected. The dashed lines show the structural efficiencies that are realized when the effect of gussets and rivets is included in the calculations.

Structural-efficiency curves for diagonal-tension webs with single and double uprights as given in reference 1 are shown in figure 2. These curves are plotted for three values of d/h, where d is the upright spacing and h is the effective depth of the beam. The structural-efficiency curves for Pratt and Warren truss webs, corrected for rivet and gusset effects, are replotted in figure 2 for ease of comparison.

DISCUSSION

A general comparison can be made of the structural efficiencies of Pratt and Warren truss webs and diagonal-tension webs by use of figure 2. It should be pointed out that slightly higher efficiencies may be obtained both for the diagonal-tension webs and for the two truss webs by increasing the width-thickness ratios of the web uprights or truss members. The increase in efficiency, however, should be about the same for both types of construction and therefore should not affect the comparison.

Inspection of the structural-efficiency curves for diagonal-tension webs (fig. 2) shows that, over the range of values of d/h investigated, a web with $\frac{d}{h} = 0.25$ generally is the most efficient. Because the efficiency curves for truss webs shown in this figure are for the most efficient Pratt and Warren truss webs, the most efficient diagonal-tension web $\left(\frac{d}{h} = 0.25\right)$ will be used in the comparison. On this basis, the diagonal-tension web is a more efficient structure than the Pratt truss web and is more efficient than the Warren truss web except for values of the structural index $\sqrt{S}/h$ between approximately 4 and 7. In this range, the Warren truss web shows a slightly higher efficiency than the diagonal-tension web.

Several practical considerations affect the comparison. If a truss web were used in the construction of a wing spar, the slope of the diagonal truss members in most cases would be determined by the spacing of the wing ribs. The efficiency shown for the two truss systems, therefore, would not always be realized, because the curves in figure 2 are based on calculations using the ideal slope

for the diagonal truss members. Any material change from this ideal slope results in an appreciable drop in the truss efficiency. On the other hand, it is usually possible to use a small upright spacing in a diagonal-tension web regardless of the wing rib spacing (using intermediate uprights if necessary) and consequently to obtain a high efficiency for this web. For conventional wing ribs (vertical ribs), the efficiency of the Warren truss web is further lowered by the necessity of introducing secondary vertical members to carry the rib loads into the truss structure.

A small point in favor of the diagonal-tension web is that it is fully effective under negative loads whereas the Pratt and Warren truss webs are not. This ineffectiveness is unlikely to be critical in wing-spar construction since the negative design loads are not so large as the positive design loads.

In the final design, it is necessary to consider not only the efficiency of the web system but also the efficiency of the entire beam including the flanges. The allowable stresses of the flanges in diagonal-tension beams are lowered by secondary bending, but this effect can be made very small by reducing the spacing of the uprights. Small spacings of the uprights will also give a high efficiency for the web system, although not always the highest possible. The requirements for simultaneously obtaining high efficiency of the flanges and of the web in diagonal-tension beams are therefore not in conflict. In a beam with a Warren truss web, on the other hand, the high efficiency of the web is obtained in beams having unsupported lengths of the flanges larger than the depth of the beam. These large unsupported lengths may result in rather low allowable stresses for the flanges and therefore a lowered over-all efficiency for the beam. Any attempt to increase the efficiency of the flanges by changing the slope of the diagonals will result in a lowered efficiency of the web system. In the truss beam, then, the requirements for simultaneously obtaining high efficiency of the flanges and of the web system are in conflict. It is questionable, therefore, whether the over-all efficiency of the Warren truss beam can be made higher than that of the diagonal-tension beam even though the efficiency of the Warren truss web alone may be higher than that of the diagonal-tension web.

One factor, however, may favor the use of the truss web in spar construction. When a number of cut-outs must be made in the web for fuel lines, control cables, ducts, and other items, the structural efficiency of the diagonal-tension web is materially lowered. In this case the Warren and possibly the Pratt truss may be a more efficient design than the diagonal-tension web.

CONCLUSIONS

A comparison was made of the structural efficiencies of 24S-T aluminum-alloy Pratt and Warren truss webs and diagonal-tension webs designed on the basis of identical allowable stresses. It was concluded that the diagonal-tension web is more efficient than a truss web except for a small range in which a Warren truss web is more efficient. For complete beams (web and flanges), however, the diagonal-tension beam probably always will be more efficient than the Warren truss beam because of the low efficiency of the flanges in the Warren truss beam.

Langley Memorial Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va.

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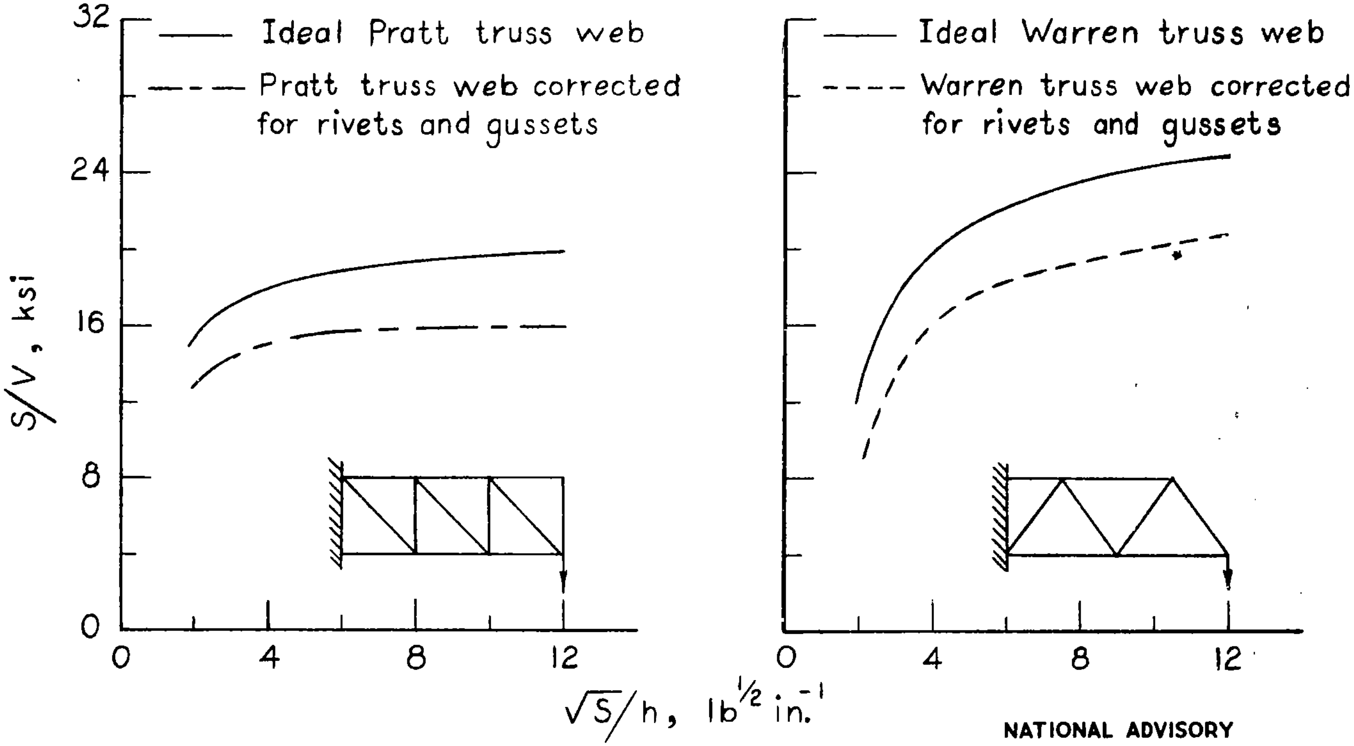

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Figure 1.- Structural efficiencies of truss webs of 24S-T aluminum alloy.

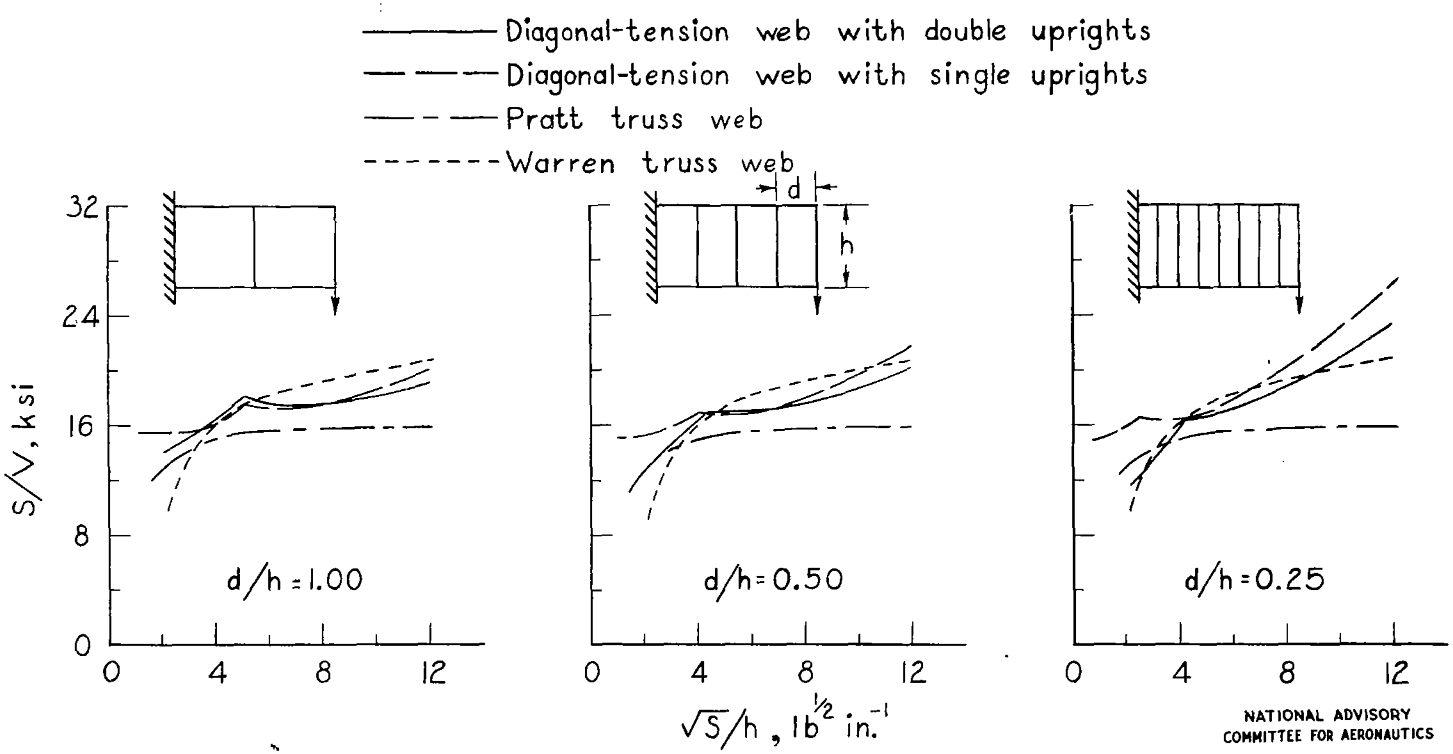

Figure 2.- Structural efficiencies of diagonal-tension webs and truss webs of 24S-T aluminum alloy. (The values of d/h apply only to the diagonal-tension webs.)